Shut Down Schedule Optimization with Outdoor Humidity Level

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ABSTRACT

The use of a shutdown schedule on air handling units in an office or classroom building during mostly unoccupied times, such as the late evening and early morning hours, can be a quick and effective method to reduce energy consumption. Implementing a shutdown schedule is often a simple matter of changing the control scheme. However, while outside air dampers can usually be closed using control systems, many buildings have manually controlled exhaust fans that cannot be turned off through the use of the control program. When air handling units are off, the exhaust fans create an overall negative building pressure, resulting in the infiltration of untreated outside air. When outside air is drier than the desired indoor humidity level, the infiltrated air may not have significant negative effects on the operation and comfort of the building. However, when outside air humidity levels exceed the desired indoor humidity level, comfort inside the building may be hard to restore unless the air handling units are restarted in a timely manner. If the indoor humidity gets too high, the building itself may experience damage from mold and other related problems.

Because of these circumstances, most buildings utilize one of two less effective control strategies. Either the air handling units run continuously in order to prevent humid air from entering the building, or the units are shut down based on the time of day alone, which can result in the problems mentioned when the outdoor humidity is high. This paper suggests a methodology to optimize the shutdown schedule and control the outside air intake based on the humidity level of the outside air. This methodology has the potential to produce significant energy savings in buildings whose air handling units run around-the-clock in addition to creating a better environment in buildings whose air handling unit schedules are based strictly on the time of day. This methodology may not be suitable for buildings with clean rooms or laboratories.

This paper also presents the potential savings from using the methodology on a university campus, and shows the potential of applying the methodology to different climate areas of the United States.

INTRODUCTION

A debate exists among engineers regarding shutdown schedules of air handling units in commercial buildings where the exhaust fans cannot be shutdown. Some believe that using a shutdown schedule is a quick and easy way to save energy, and therefore money. They insist that these benefits are of sufficient worth to offset any minor consequences of the shutdown schedule. Those of the opposite opinion contend that shutting off outside airflow into the building is in violation of building codes because shutdowns result in the infiltration of untreated, potentially humid outside air, which can increase indoor humidity levels and can lead to indoor air quality problems such as mold. A lack of constant fresh air into the building, they argue, can lead to health problems and eventually to lawsuits, which could end up costing much more than the amount saved from reduced operation (Chen, et al. 2002 & 2004; Harriman, et al. 2001). Likewise, if indoor humidity levels increase too much, it may take more energy to both decrease the temperature and remove the humidity upon restart than the energy saved from reducing the operation time. Thus, an effective method of controlling humidity levels is needed when implementing shutdown schedules in order to achieve energy savings and maintain comfortable, healthy building conditions (Achenbach, 1984).

Since air infiltration may occur during a shutdown, shutdown schedules will vary based on climate areas. Because of air infiltration, it is important to qualify outdoor climates and their effects on infiltration. Hedrick and Shirey (1998) have devised a method for defining a humid climate based on weather data gathered over an entire year for certain areas. This paper will examine the use of a humidity control schedule in various climate areas.

When devising a humidity control method, a common concern is the availability of humidistats and their ability to control and monitor humidity levels. To ensure acceptable humidity levels throughout a building, it would be advisable to have at least one humidistat available on each floor of the building or at least one humidistat for each air handling unit located in the area that is served by the individual air handling unit. Most buildings are not equipped with this number of humidistats and would require an initial investment for purchase, installation, and connection of the needed humidistats to the control system. For a typical building, this may be a low to moderate investment. For a large campus or skyscraper, however, this investment would be substantial, and could take years to fully implement. To solve this problem, a humidity control method has been devised for the implementation of a shutdown schedule that requires only one outside air humidistat for any number and size of buildings on a common control system. This method is based on theoretical calculations as opposed to empirical data, and involves several assumptions.

For the purpose of this paper, the discussion of a shutdown schedule assumes that the shutdowns occur at nighttime and on weekends when the building is unoccupied. It is also assumed that no barriers exist to prevent the HVAC equipment from being placed on a shutdown schedule from a load requirement standpoint—i.e. no computer rooms or other spaces require constant conditioned air. Different steps can be taken in these situations which are described in this paper. Additionally, differing ranges of acceptable indoor humidity levels sometimes exist. This paper assumes that acceptable levels are below 60% relative humidity for typical room temperatures.

METHODOLOGY

<u>Introduction to Methodology</u>

While commissioning a building on the Texas A&M campus, engineers found that the areas served by many of the air handling units were unoccupied during nighttime and weekend hours. This created a large potential for savings by turning off the air handling units during these hours. However, since the climate in College Station, Texas is considered hot and humid, concerns arose that humid air would infiltrate the building when the air handling units were off, creating humidity problems in the building. The concerns were due to the fact that while the air handling units could be cycled on and off using DDC controls, the exhaust fans throughout the building were manually controlled and would continue to run all night.

The optimal solution to a problem like this would be to install remote DDC control for the exhaust fan. However, this solution would be expensive, and some building proctors may not be willing or able to fund it. If the exhaust fans continue to be manually controlled, it is necessary to ensure that the air handling units (or outside air intakes) are only shut down during hours when the outdoor air humidity is no greater than the desired indoor humidity. This can be accomplished by following the procedure outlined below.

<u>Procedure</u>

1. Examine the dynamic weather data (values and patterns)
2. Develop the criteria to be used to implement the control method based on the weather data and unoccupied periods in the building.
3. Select the weather parameters that will be used to evaluate the control method
4. Carry out the control method in the building via the control program.
5. Estimate resultant savings.

A brief explanation is given below for each step in the procedure and how each step has been applied to the College Station study.

<u>Examine the Dynamic Weather Data (Values and Patterns)</u>

First, weather data must be obtained and plotted for the area where the building is located. This will help determine how many hours the air handling units may be shut down for the building. For this study the weather data in College Station was used. The absolute humidity for College Station over time is plotted in Figure 1. As can be seen in the plot, while humidity is lower overall in the winter months than in the summer months, considerable variation in the humidity occurs from day to day. Therefore, it is necessary to have a humidity sensor in place rather than allowing air to infiltrate during certain seasons. More explanation of how absolute humidity is determined appears in the "Absolute Humidity Considerations" section.

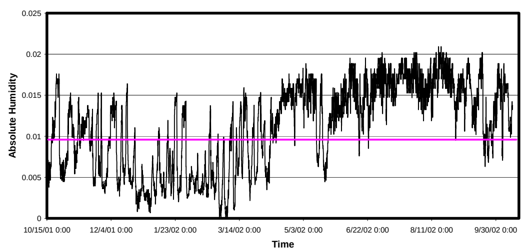

Figure 1. Absolute Humidity for a One-Year Period for College Station

<u>Develop the Criteria to be Used to Implement the Control Method</u>

Next, the dry bulb temperature and relative humidity levels desired in the indoor space should be chosen. This will correspond with the maximum humidity level of outside air that can infiltrate into the building without causing comfort problems. Additionally, minimum and maximum allowable temperatures of infiltrating air may be chosen. Even if air is dry, it may significantly impact the interior environment if it is either extremely hot or cold.

<u>Select the Weather Parameters to Evaluate the Control Method</u>

When selecting weather parameters that will be used, it is important to consider outside air humidity levels, dry bulb temperature, and wet bulb temperature. When evaluating humidity, it is necessary to use absolute humidity, which is the actual amount of water in the air, rather than relative humidity. Therefore, the absolute humidity corresponding to the criteria chosen is step 2 must be used for all calculations and comparisons. For this analysis an absolute humidity value of W=0.0096 pounds of water vapor per pound of dry air, which corresponds to a dew point temperature of 56°F, was selected. The line corresponding to W=0.0096 pounds of water vapor per pound of dry air is the top horizontal line shown on the psychrometric chart in Figure 2. The line corresponding to this absolute humidity value is also shown on the College Station absolute humidity plot in Figure 1.

As stated, it is also necessary to look at the outside air dry bulb temperature so that extremely cold or hot air does not infiltrate the building. For this analysis it has been decided to select 40°F as the minimum temperature at which to allow infiltration. Rather than selecting a maximum dry bulb temperature, a maximum wet bulb temperature will be chosen. A wet bulb temperature of less than 63°F has been selected. This wet bulb temperature corresponds to the wet bulb temperature at our desired room condition. The 63°F wet bulb temperature limit will make sure that the air entering the building has less enthalpy than the desired room condition, even if the dry bulb temperature is greater than the desired room temperature. The psychrometric chart in Figure 3 outlines the selected weather parameters of a) absolute humidity less than 0.0096 pounds of water vapor per pound of dry air, b) dry bulb temperature greater than 40°F, and c) wet bulb temperature less than 63°F that have been selected to evaluate the method.

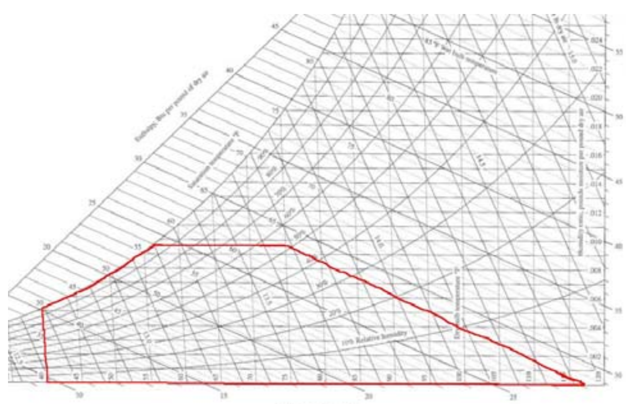

Figure 2. Psychrometric Chart with AHU Shutdown Criteria Shown

Table 1 gives the amount of hours that meet all criteria previously developed for College Station and the total number of hours available for AHU shutdown. Almost 3000 of the 8760 hours of the year meet the chosen criteria (34%). Of these hours, 62.7% fall during night or weekend hours when buildings are unoccupied. By shutting down the air handling units during these hours, a considerable amount of energy could be saved.

Table 1. Hours that fit all shutdown criteria in College Station

Location	Total Hours (Day & Night)	Night-time hours	Week-end Hours	Total Shut-down Hours
College Station	2994	1431	447	1878

<u>Carry Out the Control Method in the Building via the Control Program</u>

While some air handling units must be run continuously due to space load requirements, others may be turned off during the nights and weekends for energy savings if the weather conditions meet the designated criteria.

For air handling units that must be run continuously, the outside air damper may be modulated to close during the nighttime and weekends or, if it works better for a particular application, an economizer cycle may be implemented. Air handling units that can be shut down during unoccupied periods should be if the criteria are met. Although the exhaust system will continue to run, the infiltrating outside air will not create a humid interior environment if it is dry. The control method for both air handling unit scenarios is summarized in Table 2, and a flow chart of the actions that should be taken is shown in Figure 3.

Table 2. Fan and Outside Air Damper Schedules during Hours that Meet Chosen Criteria

	Fan	OA Damper	Exhaust
Existing Conditions	24/7	Open 24/7	24/7
Proposition 1: AHU that must run 24/7 due to space load requirement	24/7	If Temp>60°F Weekdays: Open Weeknights: Closed Weekends: Closed	24/7
Proposition 2: AHU that may be shut down	Weekdays: On. Weeknights: Off Weekends: Off	Weekdays: Open Weeknights and weekends: Irrelevant	24/7

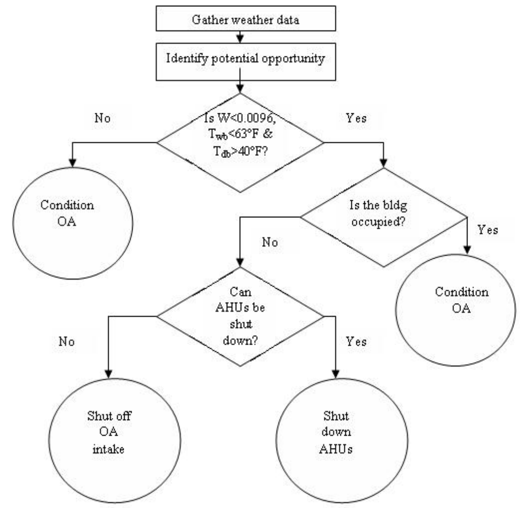

Figure 3. Flowchart: Can AHUs be Shut Down?

Some buildings will be better suited for this control method than others. For instance, dormitories or buildings with laboratories may not be good candidates for applying this method. On a university campus, the best-suited buildings are office and classroom buildings. On the Texas A&M campus, 87 of the 174 buildings are of this type. Of these 87 buildings, 73 (or 84%) of them have manually controlled exhaust fans. Only 10% of the buildings have DDC control on the exhaust fans. Of the buildings with manually controlled exhaust fans, 68 do not have a shutdown schedule currently in place. These buildings could see significant savings from implementing this commissioning measure. If 39% of the buildings on campus (68/174) were to use this shut down schedule during low-humidity hours, the university would see considerable savings.

By implementing changes to the control program, eligible air handling units can be shut down during times that meet the criteria selected, and outside air dampers on air handling units that must be run continuously may be closed. A humidity sensor will need to be in place and connected to the control system in order to carry out the procedure.

Once the changes to the control program are in place the function of the air handling system will change. The weather data and air handling unit operation schedule will need to be verified to ensure that the air handling units only shut down when the resulting infiltration will not negatively affect the building.

Estimate Resultant Savings

The savings resulting from the new control method should be calculated, and the feasibility of applying the control method to other buildings should be evaluated.

The optimized shut down schedule method based on various weather conditions was implemented in two buildings on the Texas A&M University campus. The Langford Architecture B building, one of these two buildings, is a 28,545 square foot classroom and office building with two single-duct air handling units. It is estimated that between $8000 and $9,000 a year will be saved from shutting down the air handling units in this building during unoccupied times when outdoor conditions meet the chosen criteria. These savings are based on the assumption that the air handling unit constantly runs and does not utilize an economizer cycle. This estimate gives a savings of 20-30 cents per square foot. With a campus the size of Texas A&M that has over 68 buildings with areas that could utilize this method, considerable savings could be achieved by implementing this method.

ABSOLUTE HUMIDITY FORMULA

Simplified Absolute Humidity Formula

To control the air handling unit schedule based on absolute humidity, it is necessary to have a humidity sensor.

Both absolute and relative humidity sensors are available on the market today. If an absolute humidity sensor is available, it can be used to implement the methodology. However, if only a relative humidity sensor is available there is no reason to purchase an absolute humidity sensor since the absolute humidity can be calculated given the dry bulb temperature and relative humidity or given the dew point temperature. In the ASHRAE handbook, the equations for absolute humidity level are complicated and involve many parameters such as the saturation pressure. For the purposes of programming, it is necessary to find a simple equation to relate absolute humidity level to dry bulb temperature and relative humidity levels. The traditional formula for absolute humidity is

$$W = \frac{0.622 P_w}{P - P_w} \tag{1}$$

Where

$$P_W = \phi P_{sat} \tag{2}$$

And

W= absolute humidity level
P= atmospheric pressure
ϕ = relative humidity
P_{sat}= saturation pressure
P_w= partial pressure of water vapor

Curve fits from the steam tables were used to find P_{sat} as a function of dry bulb temperature and the resulting equation was plugged into the absolute humidity formula to get W in terms of dry bulb temperature and relative humidity.

$$W = \frac{0.622\phi * (1.7924*10^{-6} T_{db}{}^3 - 1.7979*10^{-4} T_{db}{}^2 + 0.11 T_{db} - 0.14456)}{14.7 - \phi(1.7924*10^{-6} T_{db}{}^3 - 1.7979*10^{-4} T_{db}{}^2 + 0.11 T_{db} - 0.14456)} \tag{3}$$

While this equation allows the calculation in terms of relative humidity and dry bulb temperature, it involves many terms and is difficult to implement in a control program. Fortunately, knowing dew point temperature can directly give the absolute humidity value. A curve fit was performed using the psychrometric chart to find an equation for the absolute humidity in terms of dew point temperature. This equation allows easy implementation into the control program. The result is

$$W = 5.947*10^{-8} T_{dp}{}^3 - 3.849*10^{-6} T_{dp}{}^2 + 2.24*10^{-4} T_{dp} - 1.38*10^{-3} \tag{4}$$

Where

T_{dp}= dew point temperature (°F)

Dew Point Rules of Thumb

If only the dry bulb temperature and relative humidity are known, it is necessary to quickly calculate dew point temperature. In order to do this, dew point rules-of-thumb were calculated. At given relative humidity levels, the dew point temperatures at dry bulb temperatures ranging from 50-95°F were tabulated. The difference between the dry bulb and dew point temperatures were calculated, and the average difference at each relative humidity was found. For instance, the average difference at 60% RH is 14.6°F, with a minimum difference of 13.3°F at 50°F dry bulb and a maximum difference of 16.1°F at 95°F dry bulb. The differences as a function of relative humidity are graphed in Figure 4, and the maximum and minimum differences are graphed in order to show the potential error. As seen, the error decreases with increasing relative humidity. The resulting equation is

$$T_{db} - T_{dp} = -27.82\ln(\phi) + 0.16 \qquad (5)$$

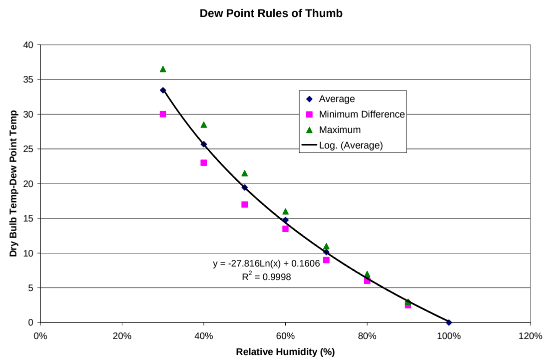

Figure 4. Dew Point Rules of Thumb Graph Showing Errors

In summary, in order to calculate absolute humidity without using an absolute humidity sensor for the purposes of programming:

1. Measure dry bulb temperature and relative humidity using the available sensors.
2. Use equation (5) to calculate the dew point temperature
3. Use equation (4) to calculate absolute humidity

Humidity Sensor Accuracy

Ensure that the humidity sensor is well calibrated at all times so that the measurements taken will be accurate. If incorrect measurements are taken, humidity problems could result by letting excessively humid air infiltrate the building.

Number of Humidity Sensors Needed

Only one accurate humidity sensor is needed on a given controls system; it can be used for all buildings on the system.

APPLICATION

The question arises as to which areas are best suited to implement the proposed methodology. In low humidity areas, air quality engineers are not concerned with humidity problems and could use a duty cycle or other scheme that would be much more cost-effective than installing humidity sensors to monitor the outside air and shut down air handling units as appropriate. Buildings in humid climates, however, must be concerned with humidity issues. The question then would be what exactly is a humid climate, and in what areas of the United States should this methodology be seriously considered?

Humid Climates

ASHRAE 2005 Fundamentals defines a warm, humid climate as "one where one or both of the following conditions occur: (1) a 67°F or higher wet-bulb temperature for 3000 or more hours during the warmest six consecutive months of the year, or (2) a 73°F or higher wet-bulb temperature for 1500 or more hours during the warmest six consecutive months of the year." The grey area shown in Figure 5 is the area in which these conditions exist. Air quality engineers in this area will certainly be concerned with humidity problems and could most likely benefit from using this method.

Figure 5. Area defined by ASHRAE to be Warm and Humid

Hedrick, in his research, found a better definition of a humid climate to be, "one which, during the hottest six months of the year, the total grain-hours above 78 gr/lb exceeds 55,000." His study examined a number of weather parameters to see how each correlated to the degree of humidity problems experienced. This parameter was found to best define a "humid climate" with regard to humidity problems. Cities that fall into this category include Miami, Shreveport, Montgomery, and Waco, which would have been included using the ASHRAE definition. However, this definition also encompasses Little Rock, Tulsa, Nashville, Richmond, and St. Louis (See Figure 6). Considering that his findings were based on humidity problems such as mold, excessive infiltration of air into buildings in this area should be avoided unless the air is known to have low humidity. Locations both inside and outside of these two areas will be examined to see how well the methodology can be implemented in these humid climate areas.

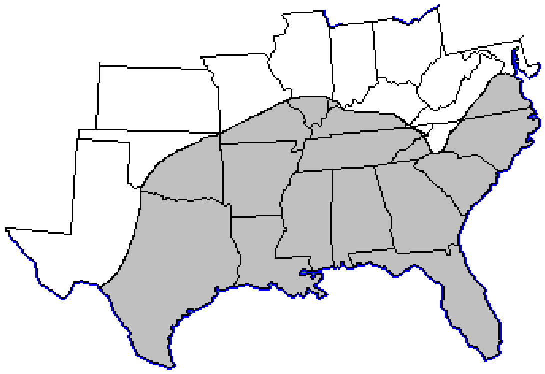

Figure 6. Warm, Humid Area According to Hedrick's Definition

Figure 7 **Error! Reference source not found.** plots the absolute humidity versus time for Houston, which is considered humid by both ASHRAE and Hedrick, and Figure 8 shows the same plot for Salt Lake City, which is not defined as being humid by either definition. The same plot for College Station can be seen in Figure 1. These time series plots can help determine if the method will be applicable in certain locations. This allows a seasonal trend of humidity for the region to easily be depicted.

The data was also used to determine the total number of hours that fit all the criteria determined previously, as well as the total number of hours per month that fit the criteria, which will help determine if a schedule can be developed from a seasonal pattern or if a sensor is required.

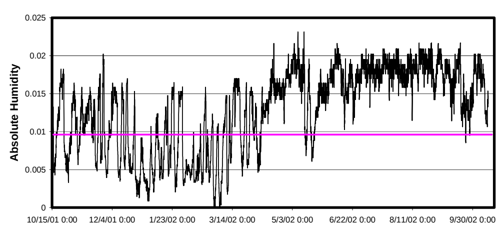

Figure 7. Houston Humidity Time Series Plot Over a Year

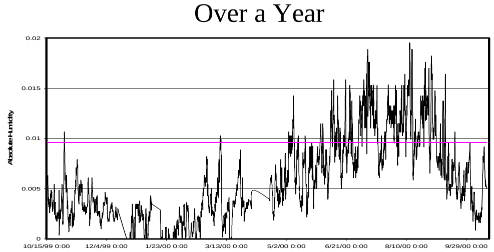

Figure 8. Salt Lake City Humidity Time Series Plot Over a Year

Table 3. Comparison of Average Humidity Conditions in Four U.S. Cities

Location	Average W (lb/lb)	Average Tdb (°F)
College Station	0.011181	68.2
Houston	0.012903	69.9
Minneapolis	0.006010	50.4
Salt Lake	0.005993	50.3

In order to examine areas that fall into both humid climate areas, only Hedrick's humid climate area, and neither humid area, bin data from 16 areas were analyzed and divided into three categories: humid by ASHRAE definition, humid by Hedrick's definition, and Not-Humid. The locations are mapped in Figure 9.

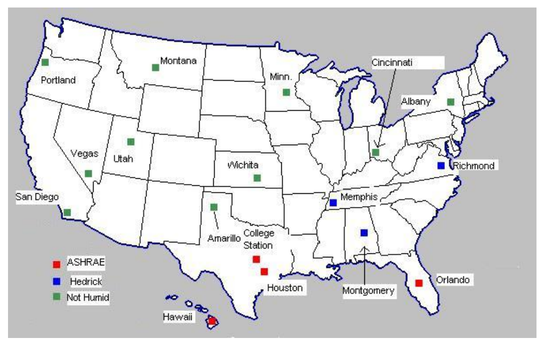

Figure 9. Areas Analyzed for Potential Methodology Implementation

The criteria developed earlier during the College Station study of a) an absolute humidity value less than 0.0096, b) an outside air dry bulb temperature of 40°F or warmer, and c) a wet bulb temperature less than 63°F, will be used to determine the possible number of shutdown hours for air handling units in various locations. It is important to note that different criteria can be established by the engineer for specific cases as described in the Methodology section.

The number of hours that fit all three AHU shutdown criteria was determined for various locations throughout the U.S. and can be found in Table 4. Locations such as Albany, though dry, had very few hours during which the methodology can be implemented due to a large number of nights and weekends with air temperatures less than 40°F and/or wet bulb temperatures greater than 63°F. Mild climate areas such as Portland and San Diego exhibit a large amount of hours wherein this scheme could be implemented.

Table 4. Number of Hours That Satisfy AHU Shutdown Criteria for 16 U.S. Cities

Hours that Fit All Three Criteria				
Location	Total Hours (Day & Night)	Nighttime Hours	Weekend Hours	Total Shut-Down Hours (Night + Weekend)
Hawaii	10	8	1	9
Orlando	2223	1361	246	1607
College Station	2994	1431	447	1878
Houston	2745	1556	340	1896
Minneapolis	3061	1536	436	1972
Wichita	3343	1634	488	2122
Albany	3510	1771	497	2268
Montgomery	3454	1812	469	2281
Cincinnati	3535	1804	495	2299
Memphis	3529	1823	487	2310
Richmond	3776	1880	542	2422
Amarillo	4071	1884	625	2509
Montana	5015	2322	769	3091
Utah	5766	2765	857	3622
Las Vegas	6155	3055	886	3941
San Diego	6317	3331	853	4184
Portland	7167	3544	1035	4579

For hot and humid climates, such as Houston, the air is often too humid in the summer, and the methodology will work best during the fall, spring, and winter as seen in Figure 7. In cold climates, such as Minneapolis, the winter months are too cold to satisfy the criteria. As seen for Salt Lake City in Figure 8, most of the hours where the method can be applied are in the spring and fall. In mild climates, such as San Diego, the majority of the hours year-round fall within the criteria. This method appears to work extremely well in this area. However, since almost all of the hours have low humidity in this area, a different method could potentially be utilized that would save more money than this method.

From the bin data that was analyzed, Orlando, College Station, Houston, Montgomery, Memphis, and Richmond all fall into Hedrick's humid climate area. As seen from Table 4, the areas that fall into only the ASHRAE humid climate area will benefit from the methodology by saving some money and preventing humidity problems; however, Montgomery, Memphis, and Richmond (or the cities that Hedrick finds to be in humid climates and ASHRAE does not) all have many hours where the air handling units can be shut down. By using this method in these areas much energy could be saved while preventing the humidity problems that can occur in these areas. All cities in Hedrick's humid climate area could be good candidates for using the methodology. It is recommended that when commissioning a building in this warm, humid area, this method be looked at as a potential energy-saving measure. It is recommended that the engineer always analyze the weather data in his or her specific area of interest and calculate the savings potential before implementing these measures. It is expected that monitoring humidity levels before allowing unconditioned air to infiltrate the building will significantly improve indoor air quality.

Dry Climates

The locations analyzed that do not fall into the humid climate category typically are not concerned about indoor humidity level problems during the majority of the year. Though San Diego and Portland show the most hours where the shut down method could be used, they do not need to utilize it year-round because most months have no conditions which pose humidity problems. However, as seen in Figure 8 with Salt Lake City, there are some hours during the summer where in humid conditions can cause problems in typically dry areas. In these areas the weather data should be analyzed and a schedule of this type should be implemented during those months where humid conditions are present.

CONCLUSIONS

Considerable energy savings can be achieved by using an air handling unit shut down schedule for office and classroom buildings. However, if manually controlled exhaust fans are running while the air handling units are shut down, the negative pressure generated in the building will cause infiltration of unconditioned outside air. By using a humidity sensor to monitor the outside air humidity level, the air handling units may be shut down when the outside air meets chosen criteria. This method will result in considerable energy savings, while ensuring that indoor humidity levels remain low.

This methodology is recommended for any areas where there is concern about humidity problems inside buildings. It can be utilized for any building which is unoccupied during nighttime and weekend hours, has no sensitive areas inside the building which require the air handling units to constantly run (such as special laboratories), and has DDC control. Any locations where humidity problems are a concern should look at conditions to see if this is a useful method.

In order to implement the methodology, absolute humidity values are needed. These can be measured with an absolute humidity sensor or can be calculated using measurements from dry bulb temperature and relative humidity sensors. The outlined approach can be used to conveniently find the absolute humidity value for the purpose of program implementation.

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